Designation of Magnetic Valve Actuator in Electromagnetic-Clutch-By-Wire

Yunchao Yin, Jinyu Qu, Pan Zhang, Shenchao Zhu

***Abstract*— Magnetic value's construction parameters are designed basing on the working character and working principal of electromagnetic-clutch-by-wire. And the simulation result, which is calculated by the shifting time model, established in MATLAB/Simulink, shows that the transmission-by-wire's shifting time satisfied the requirement of automatic transmission.**

***Index Terms*— Electromagnetic-Clutch-By-Wire, Simulink, Construction Designation, shifting time**

I. INTRODUCTION

Transmission-by-wire (TBW) is a kind of new structure form automatic transmission, which is of high transmission efficiency and simple construction [1]. The TBW system is one of the most important parts in electronic vehicle (EV) [1-3], where the electromagnetic-clutch-by-wire (ECBW) is the key component.

Nowadays， the existing vehicle clutches mainly include dry-friction clutch, wet multi-plate hydraulic clutch, wet multi-plate electromagnetic clutch and dry multi-plate electromagnetic clutch. While, dry-friction clutch and wet multi-plate hydraulic clutch have the shortcomings of over-huge volume, low rotating speed, high energy consumption and cannot be controlled by wire; wet multi-plate electromagnetic clutch and dry multi-plate electromagnetic clutch are disadvantaged in over-huge volume, low rotating speed and high cost, even if they could be controlled by wire, they cannot satisfy the working requirement of EV automatic transmission.

II. THE ARRANGEMENT AND CONSTRUCTION DESIGN OF MAGNETIC VALVE ACTUATOR IN ECBW

A. Arrangement of electromagnetic coil

A new type construction of electromagnetic-clutch-by-wire (ECBW) is proposed in this paper [4]. In order to make full use of the structure space and keep the dynamic balance of electromagnetic clutch, four electromagnetic coils and two thrust pin guide sleeve bearing holes are arranged in symmetrical balance on the shell of electromagnetic clutch. The four electromagnetic coils are connected in series, where one end is power input connected with slip ring, the other end connects with electrical ground. Two thrust pin guide sleeves are inserted into their bearing holes. The specific structure is shown as Fig.1.

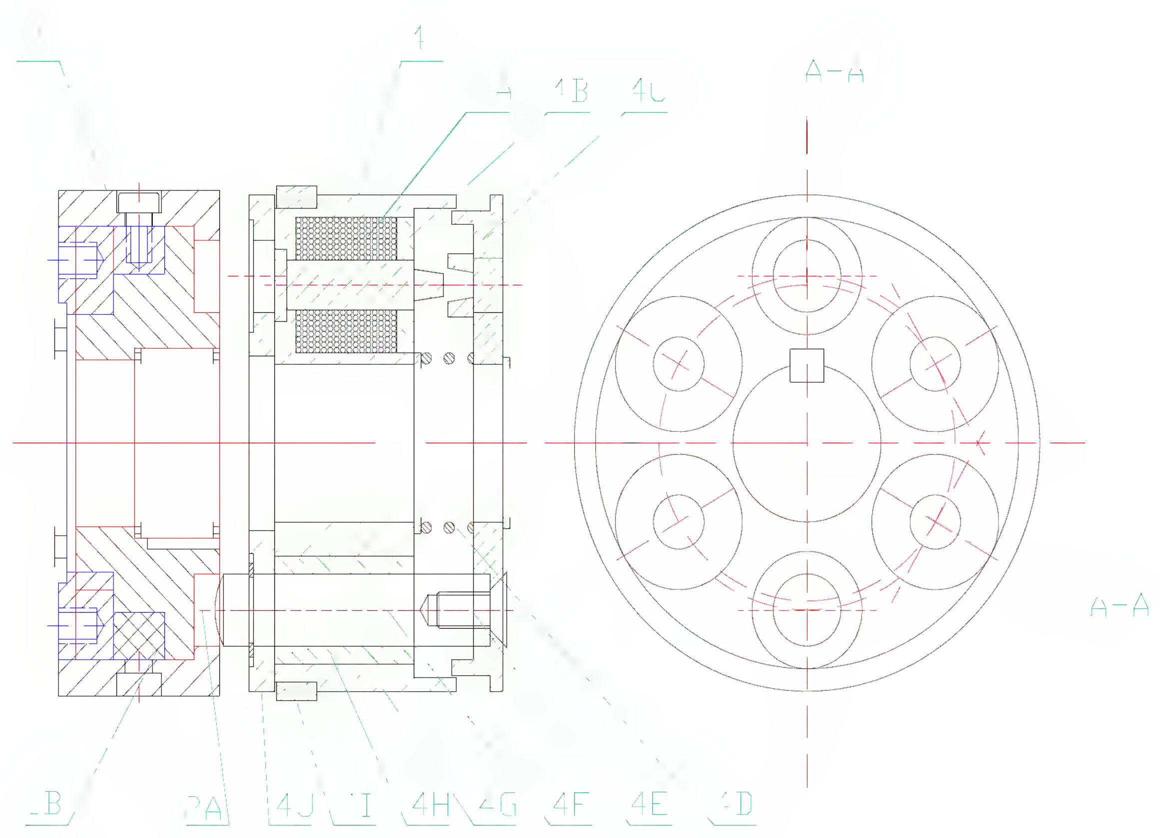

Fig.1 The construction of ECBW

B. The construction designation of electromagnetic valve actuator

The new ECBW structure proposed in this paper consists of buffer disc assembly(2), groove(2A), rubber bumper(2B), electromagnetic clutch assembly(4), electromagnetic coil(4A), electromagnet(4B), balance disc(4C), return spring(4D), fixing bolt (4E), sleeve(4H), stud-by-wire(4F), shell(4G), slip ring(4I) and balance disc(4J). When the electromagnetic valve is energized, there will be magnetic field generated around electromagnet, the balance disc will move to left with electromagnetic force overcoming the resistant force of return spring. And the stud-by-wire on balance disc will connect with driven disc to realize the smooth combination of ECBW.

When the electromagnetic valve is power off, the electromagnetic force will become the resistance force of stopping stud-by-wire to return, master-slave cultch will be departed under the function of return spring, to realize the fast depart of ECBW.

1) The designation of electromagnet

The knee-point m is chosen to be working point position as electromagnet material, according to magnetization curve and permeability curve of ferromagnetic materials. The magnetic inductive strength is strong enough in this point but cannot reach magnetic saturation. The iron-nickel alloy 1J46 is chosen to be the electromagnet material because of its high magnetic permeability, low coercively, good durability and stable magnetism.

2) The designation of electromagnetic coil

Copper enamel wire is chosen to make winding, the diameter of copper wire is 0.884mm, and its sectional area is 0.5027mm^2.

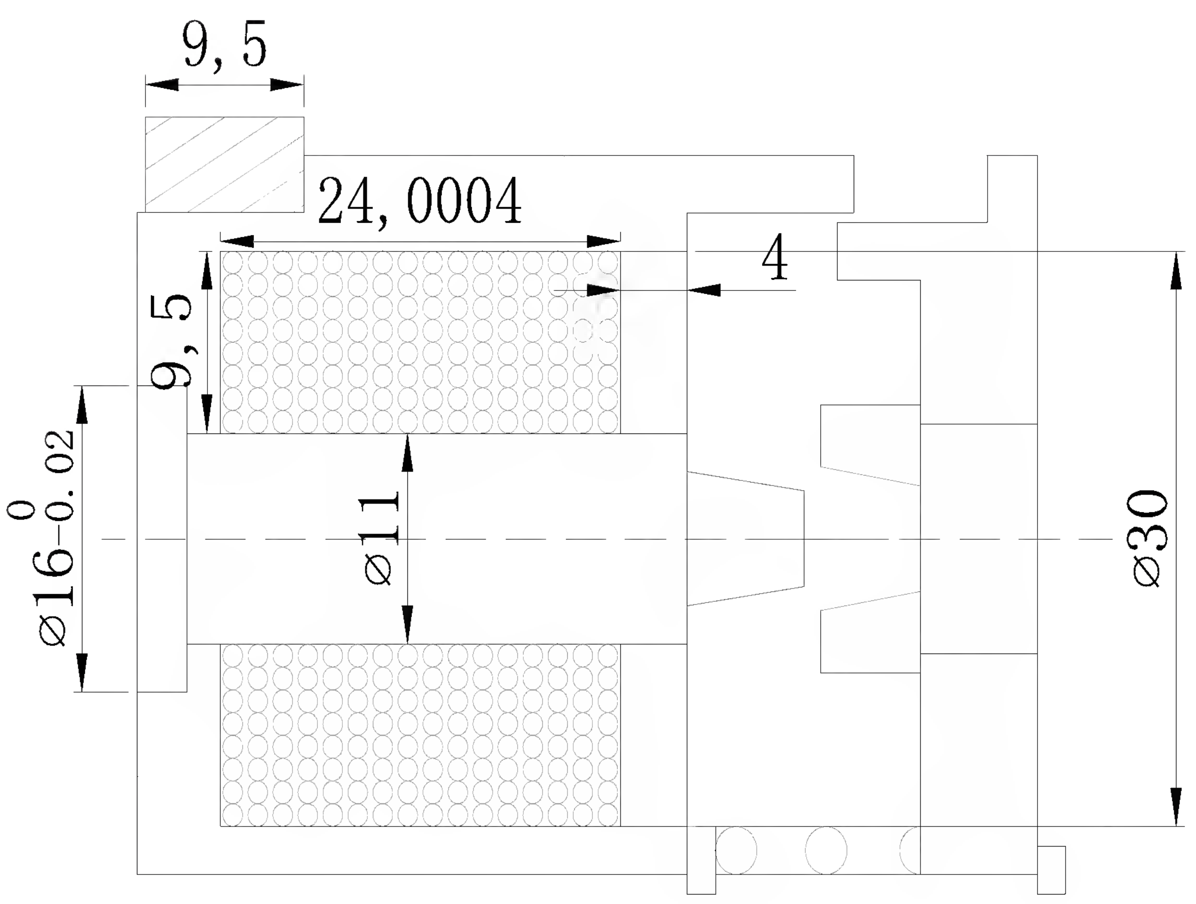

Fig.2 Construction of electromagnetic coil

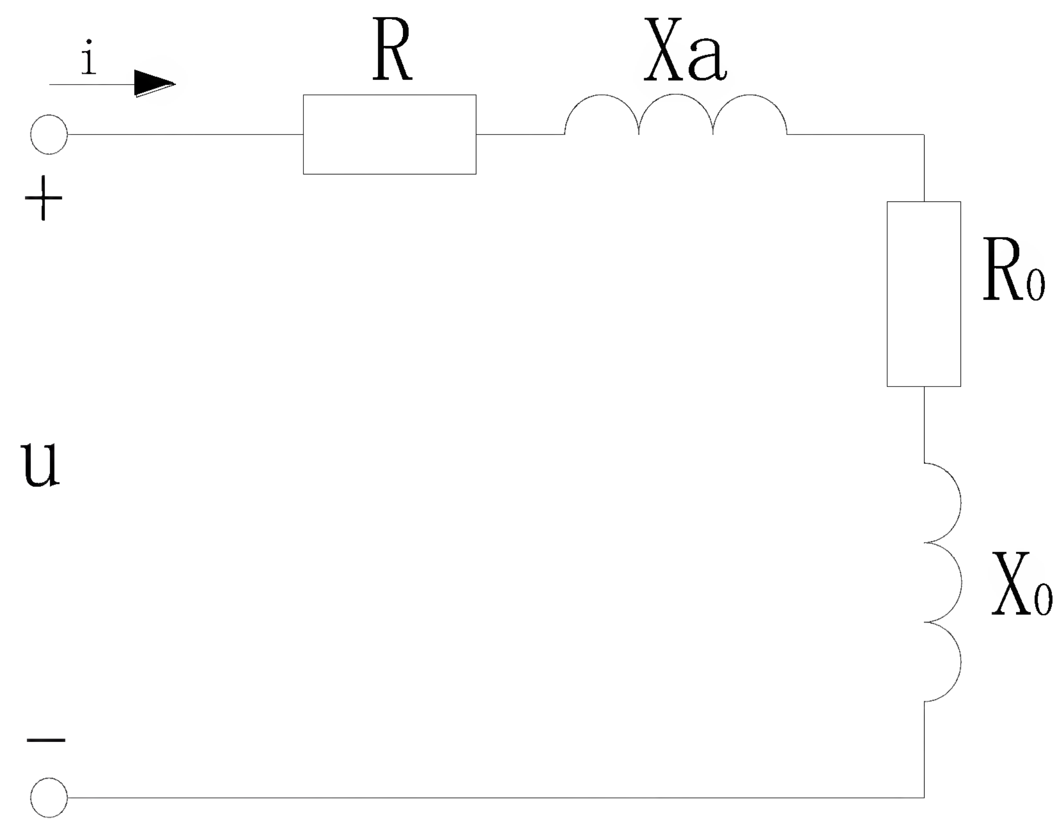

Fig.3 Equivalent circuit of electromagnetic coil

The formula for the copper wire resistance of the electromagnetic coil is:

$$R = \frac{\rho l}{S} \tag{1}$$

The length of copper wire is:

$$l = N \times C \tag{2}$$

The average perimeter of coil is:

$$C = \frac{11+30}{2} \times \pi \tag{3}$$

The empirical formula of coil inductance (without iron core) is [5]:

$$L = \frac{u_0 . N^2 . R}{l}[\pi Rk - t(0.693 + C)] \tag{4}$$

Where, $u_0$is permeability of vacuum, N is coil turns and its value is 216; R is the average radius of the coil and its value is 0.01m;l is the total length of the coil and its value is 0.24m;k is the ratio of coil's radius and length and its value is0.74; t is the thickness of coil and its value is 0.009m; C is a coefficient determined by $1/t$ and its value is 0.28. The value of L is calculated to be 3.537mH. The inductance with iron core is u_r times of that without iron core. And u_r is about 10～100, so L_l is 0.07H.

Take the effect of electromagnetic coil's inductance on the current change in to consideration, the electromagnetic coil current change formula is:

$$I_p = \frac{u}{R}(1 - e^{-\frac{R}{L}t}) \tag{5}$$

The relationship curve of electromagnetic coil's current and power-on time is shown as Fig.4. The mainly design parameters of electromagnetic clutch actuator is shown as Tab.1. The changing curve of shutdown current versus time is shown as Fig.5.

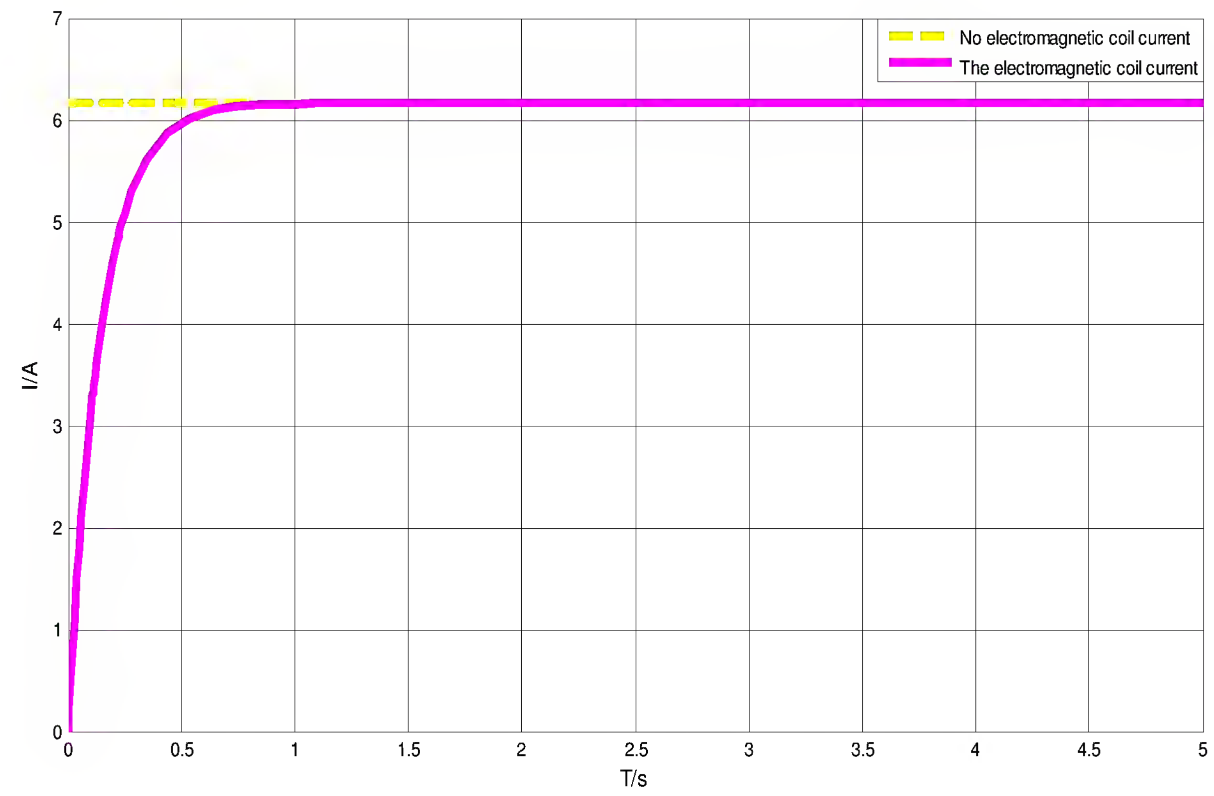

Fig.4 The relationship curve of electromagnetic coil's current and power-on time

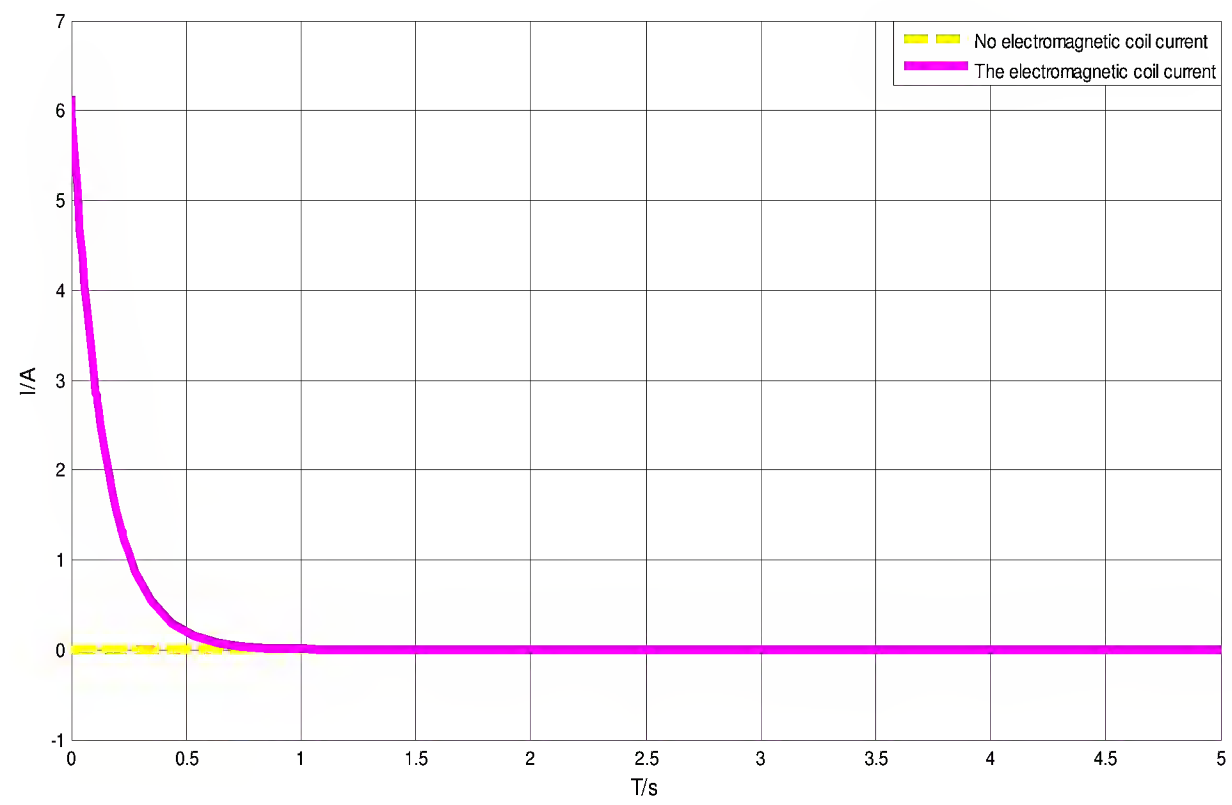

Fig.5 The changing curve of shutdown current versus time

3) The designation of return spring

According to the design requirement, the spring specification is chosen to be: free length is 12mm, compressed length is 6mm, the diameter is 2.0mm, outer diameter is 35mm, the number of active turns N_c is 2.5. The mass of stud m_1 is 0.102kg, the mass of suction disc m_2 is 0.466kg, and the mass of thrust pin balance disc m_3 is 0.373kg. So, the mathematical model of spring pressure is:

$$F_{spring} = k.s \tag{6}$$

Where, k is spring constant (*kgf/mm*), s is effective stroke of spring pressure (*mm*).

$$k = (G \times d^4)/(8 \times D_m^3 \times N_c) \tag{7}$$

$$D_m = D - d \tag{8}$$

Where, G is material's modulus of rigidity, G=8000. It can be figured out that k is 0.163 *kgf/mm*, F (6mm) = 9.584(N).

Tab.1 The mainly design parameters of electromagnetic clutch actuator

parameters	value	unit
magnetic induction /B	0--1.5	T

Permeability of vacuum / μ_0	4π*10^(-7)	Wb/A·m
magnetic path cross-sectional area /S	95*10^(-6)	m^2
number of turns/N	216	Kg
voltage/U	3*4	V
maximum current /I	6.16	A
winding resistance /R	0.487	Ω
gap length / δ	1*10^(-3)	m
Wire diameter. /d	0.8/0.884	mm
magnetic leakage coefficient /K_f	1.8	--

III. THE ESTABLISHED OF MATHEMATICAL MODEL

A. The mathematical model of electromagnetic clutch actuator

The electromagnetic force formula of designed DC solenoid electromagnet is[6-7]:

$$F = \frac{\phi^2}{2\mu_0 S} = \frac{B^2}{2\mu_0} S \qquad (9)$$

Where, φ is working air gap flux, *Wb*; B is working air gap magnetic induction, T. μ_0 is permeability of vacuum, and its value is $4\pi\times10^{-7}$Wb/A•m; S is magnetic path cross-sectional area, m^2.

In the preliminary design of the electromagnet, if the magnetic flux leakage and the air gap of connection part are ignored, considering only the core stroke gap to be the main air gap, the magnetic induction strength B of the iron core stroke (the main air gap) is:

$$B = \frac{N \cdot U}{R\delta}\mu_0 = \frac{NI}{\delta} S \qquad (10)$$

Where, N is the number of turns; I is selected as current intensity, A; U is the supply voltage, Ω; R is winding resistance,; δ is the length of the air gap, m. Usually the magnetic flux density reaches magnetic saturation when its value is15000～20000 Gs.

Take Eq.7 into Eq. 6, the following formula can be obtained:

$$F = \frac{(NI)^2\mu_0}{2\delta^2} S \qquad (11)$$

Only part of the coil magnetic potential acted on working air gap, after considering the magnetic flux leakage, formula 8 can be written as:

$$F = \frac{(NI)^2\mu_0}{2{K_f}^2\delta^2} S \qquad (12)$$

Where, K_f is the leakage coefficient, its value is ranging from1 to 10according to the condition of the magnetic composition, and it is generally take 1.2 to 5.0 in the design of electromagnetic valve. The selecting of the value has great empirical.

When the magnetic field is established gap length decreases, and the formula is:

$$(\delta - 1)^2 = \frac{(NI)^2\mu_0}{2{K_f}^2 F} S \qquad (13)$$

B. The kinematic equations of electromagnetic clutch actuator

The kinematic equation of electromagnetic valve engagement is:

$$F_c = F_a - F_e - F_r \qquad (14)$$

$$ma(t) = \frac{(NI)^2\mu_0}{2{K_f}^2\delta^2} S - 9.8\times ks - (m_1/2 + m_2/4 + m_3/4).g \qquad (15)$$

$$a(t) = \frac{1}{m}\left[\frac{(NI)^2\mu_0}{2{K_f}^2\delta^2} S - 9.8\times ks - (m_1/2 + m_2/4 + m_3/4).g\right] \qquad (16)$$

$$u(t) = \int a(t)dt \qquad (17)$$

$$s(t) = u(t)dt \qquad (18)$$

The kinematic equation of electromagnetic valve separation is：

$$F_s = F_e - F_r - F_a \qquad (19)$$

$$ma(t) = 9.8\times ks - \left[(m1/2 + m2/4 + m3/4).g + \frac{(NI)^2\mu_0}{2{K_f}^2\delta^2} S\right] \qquad (20)$$

$$u(t) = \int a(t)dt \qquad (21)$$

$$s(t) = 0.006 - u(t)dt \qquad (22)$$

IV. SIMULATION AND ANALYSIS

The model of electromagnetic clutch is established using MATLAB/Simulink according to the electromagnetic coil model, electromagnetic valve mathematical model and the kinematic equations model of electromagnetic valve engagement process and separation process [8, 9]. The model is shown as Fig.6 and Fig.7. The simulation results of electromagnetic valve engagement process sand separation process are shown as Fig.8 and Fig.9.

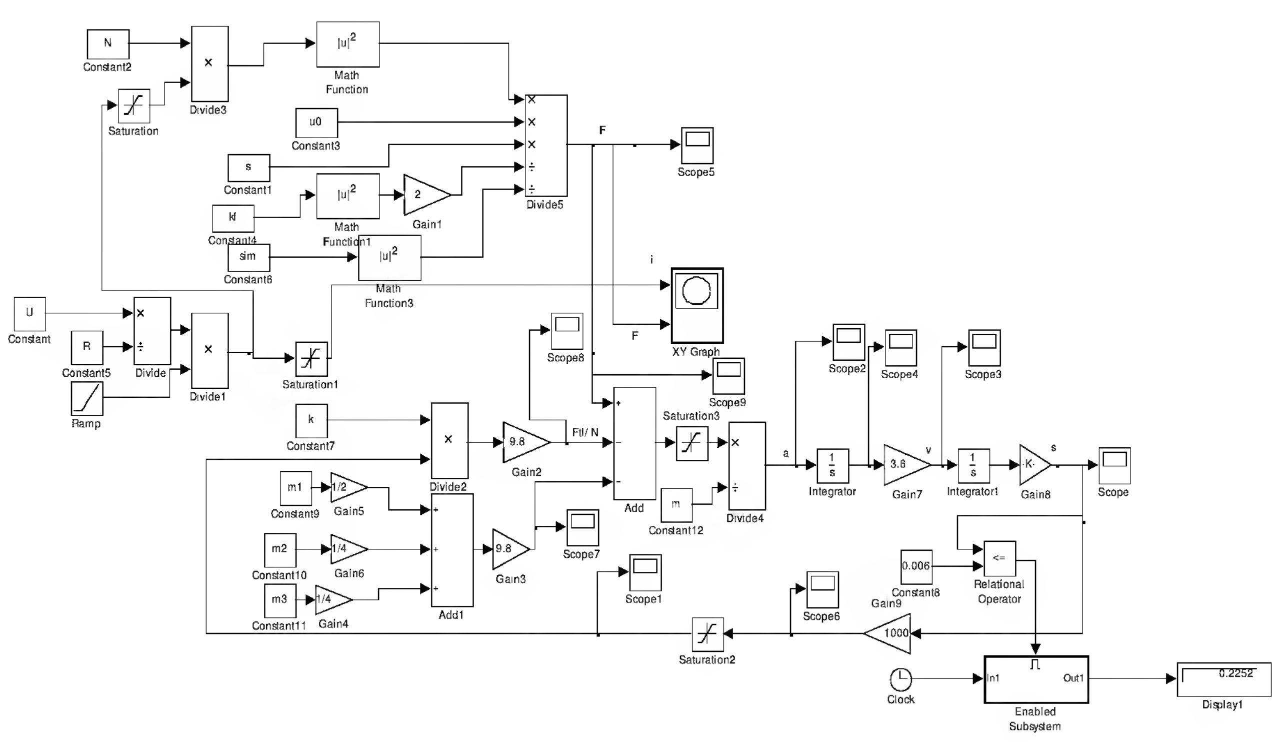

Fig.6 The relationship curve model of engagement process and time

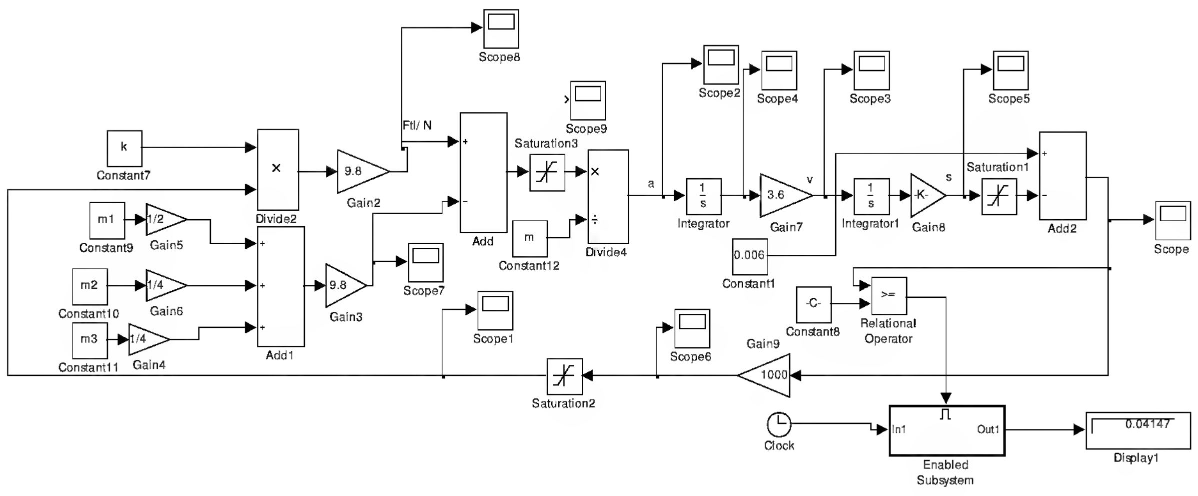

Fig.7The relationship curve model of separation process and time

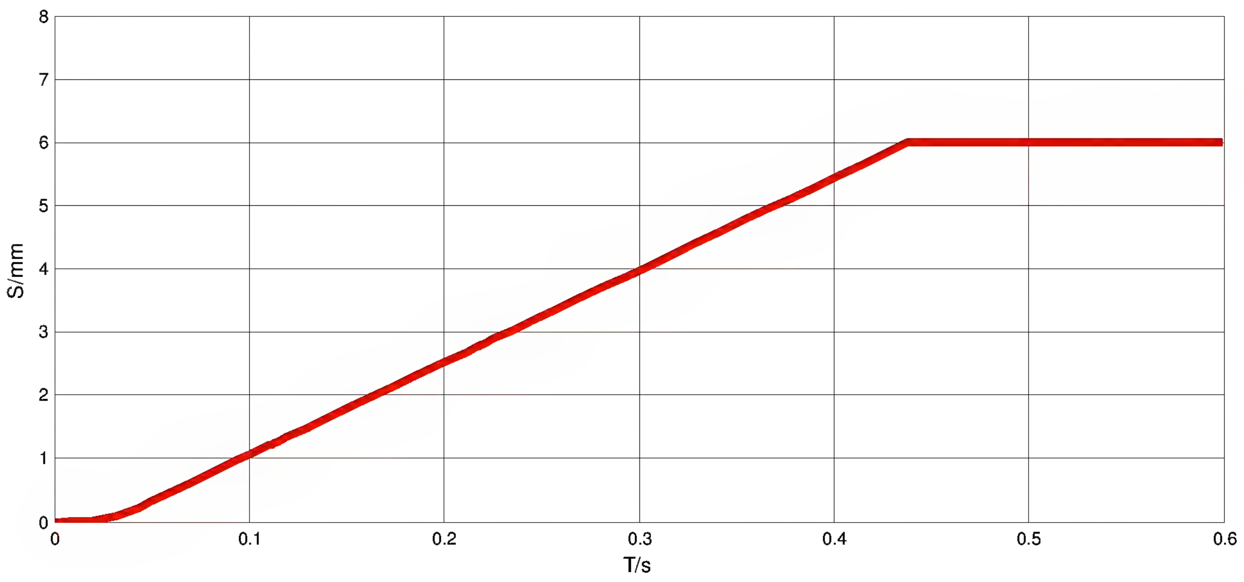

Fig.8The relationship curve of engagement process and time

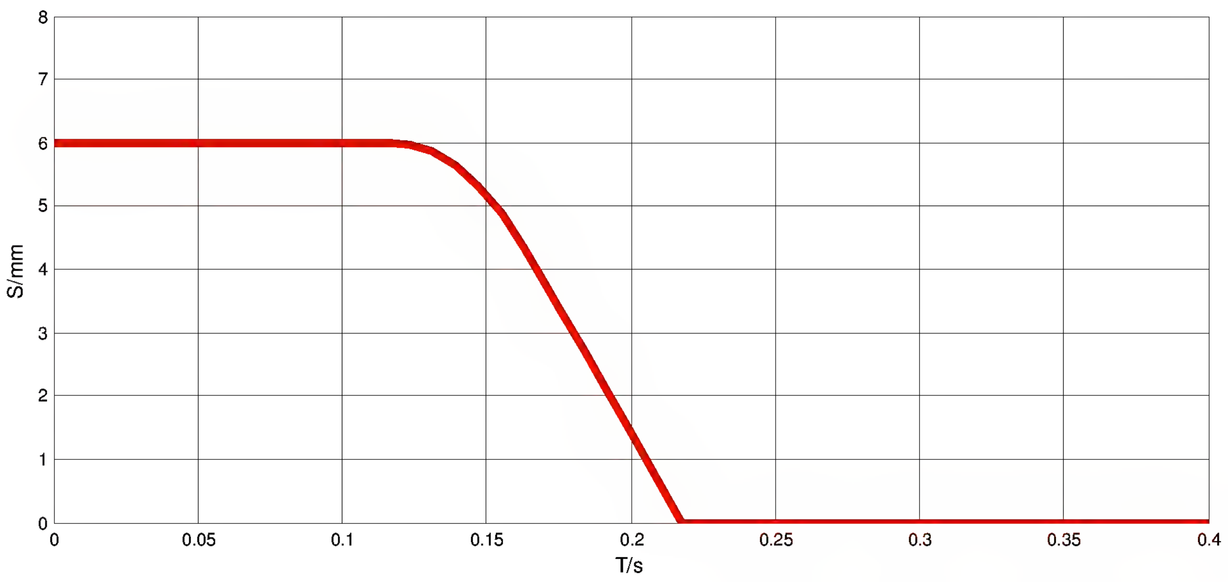

Fig.9The relationship curve of stub stroke and time in separation process

V. Conclusion

ECBW is one of the key components in the transmission-by-wire shifting process. Its specific configuration parameters are designed and calculated on the basis of analyzing its operating characteristics and working principle. The established simulation model shows that: (1) the clutch engagement time of electromagnetic clutch is 0.43s, and this satisfies the requirement of engagement process; (2) the clutch separation time of electromagnetic clutch is 0.43s, and this satisfies the requirement of separation process. This shows that the designed parameters of shifting electromagnetic valve are reasonable, and the designation has laid a good foundation for the research of TBW's gear-shifting control.

References

[1] Xiangyu Tian, Shenchao Zhu, Yunchao Yin, Jinyu Qu* ,"Research on the Transmission-By-Wire System of Electric Vehicle", International Journal of Applied Science and Mathematics, Volume 2, Issue 5, ISSN (Online): 2394-2894.

[2] Ronald K. J, "X-by-wire Automotive Systems," in Warrerulale:SAF Inxerraaxinraal_ 2009.

[3] Haggag Satem, Abidou Diaa, "An Approach to Vehicle Brake-By-Wire Optimal Control Tracking Strategy," in SAE International Journal of Passenger Cars-Mechanical Systems,1st ed. volte，2013, pp. 154-162.

[4] Jinyu Qu, Zhang Pan, Yunchao Yin., "Electric Refers to Pin Joint Device Type Three Electric Automobile Automatic Transmissions". Patent: CN204921865U.

[5] Lin An, Zhizhen Liu, Lin Zhao. "The Analysis of Magnetic Field and Suction Calculation of Electromagnetic Valve with the Method of Finite Element Method (FEM)". Journal of Shandong University (Engineering Science), 2004,06:27-31.

[6] Luliang Lou, Haizhou Wang. "The engineering calculation method of magnetic force at the design of Magnetic Valve". Missile and Space Launch Technology, 2007,01:40-45.

[7] Peng Liu, Linyun Fan, Xiuzhen Ma, Hao Wang, Yun Bai, Enzhe Song. "Study of the Response Surface Forecasting Model on High-speed Solenoid Valve Dynamic Response Characteristics". Journal of Harbin Engineering University. 2014,05:537-543.

[8] Guoqiang Liu, Demin Chen, Wei Sun, Xiaolin Guo, Dongmin Wu. "High Speed Solenoid Valve Characteristic Analysis and Control Research in Double Clutch Automatic Transmission (DCT) Control System". Chinese Hydraulic and Pneumatic, 2011,02:38-41.

[9] Jinyu Qu, Jing Liu, Yingchao Zhou, Chuanbo Ren. "The Design and Simulation of New Type Magnetic Powder Clutch Used in Vehicle" Mechanical Design and Manufacturing, 2012,12:189-191.

AUTHOR PROFILE

**Yunchao Yin**

He was born on 19th July, 1989 in Shandong province, China. He is a graduate student at the Shandong University of Technology, and major in transportation engineering. His research direction is the new energy vehicles. His research contents are the automotive electronic technology, vehicle transmission and drive by wire technology.

**Jinyu Qu**

He was born on July, 1961 in Shandong province, China. He is a professor at the Shandong University of Technology. His main research direction is automobile electronic technology and vehicle energy saving technology.

**Pan Zhang**

He was born on 7th August, 1991 in Shandong province, China. He is a graduate student at the Shandong University of Technology, and major in transportation engineering. His research direction is the new energy vehicles. His research contents are the automotive electronic technology, vehicle transmission and drive by wire technology.

**Shenchao Zhu**

He was born on 4th June, 1991 in Shandong province, China. .He is a graduate student at the Shandong University of Technology, and major in transportation engineering. His research direction is the new energy vehicles. His research contents are the automotive electronic technology, vehicle transmission and drive by wire technology.